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PILOT PLANT STUDIES TO EFFECT CHRYSOTILE ASBESTOS FIBRE REDUCTION DURING POTABLE WATER TREATMENT.

REPORT #67
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Pilot Plant Studies to Effect Chrysotile Asbestos Fibre Reduction During Potable Water Treatment

R.B. Hunsinger *
J. Lawrence **
K.J. Roberts *

Report #67

A Joint Project of the Ministry of the Environment, Ontario and the Canada Centre for Inland Waters, Department of Fisheries and Environment, Canada

* Ontario Ministry of the Environment, 135 St. Clair Avenue West, Toronto, Ontario, Canada.

** Canada Centre for Inland Waters, P.O. Box 5050, Burlington, Ontario, Canada.

Abstract

Pilot plant studies incorporating conventional potable water pre-treatment and filtration were carried out to assess asbestiform fibre removal. Problems were encountered in consistent fortification of the pilot plant feed water with sufficient asbestos to make removal measurement possible. A subjective analysis of the pilot plant runs suggests that optimized conventional water treatment is effective in reducing asbestiform fibre concentrations although many qualifications make objective conclusions unjustified.

RÉSUMÉ

Des études en usine-pilote sur l'épuration préalable et la filtration traditionnelles de l'eau potable ont permis d'évaluer l'élimination des fibres de type asbeste. Des difficultés naquirent du besoin constant de renforcer la teneur en amiante de l'eau d'alimentation de l'usine-pilote pour pouvoir effectuer les mesures. On serait tenté de déduire de l'analyse subjective des essais effectués à l'usine-pilote que l'épuration traditionnelle et optimale de l'eau permet de réduire la concentration des fibres de type asbeste. Pourtant de nombreuses restrictions ne justifient pas des conclusions objectives.

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1:0 INTRODUCTION

1:1 Background

The presence of asbestiform fibres in municipal drinking water was first reported in 1971 by Cunningham and Pontefract (1). These authors examined samples from several major cities in Eastern Canada and found fibre concentrations of between 2.0 x 10^6 and 5.9 x 10^6 fibres ℓ^{-1} where filtration plants were employed and 8.1 x 10^6 to 17.2 x 10^6 fibres ℓ^{-1}, in processes where filtration was not employed. Two subsequent surveys carried out by the Ontario Ministry of the Environment showed that the majority of the sampled water supplies contained on the order of 10^6 fibres ℓ^{-1} (2,3). Table 1 shows some representative results from these two surveys. It was on the basis of these results showing relatively high asbestos fibre concentrations in Ontario drinking water that this present research program was commenced. However, the latest survey conducted by the Ministry of the Environment early in 1976 indicates that the concentrations of fibres in all parts of the Province are generally less than 1 x 10^6 fibres ℓ^{-1} (4). Since the levels are unlikely to have decreased so drastically in such a short time period, it must be assumed that the analytical precision in one or all of the surveys is questionable.

The origin of the asbestos found in surface waters is undoubtedly a combination of natural leaching from asbestos mineral deposits and industrial contamination (either directly into water or via atmospheric emissions) from the multitude of commercial applications of the mineral, e.g. filters, automotive brake and clutch facings, floor coverings, cement and paper products, texttiles and insulation materials. Emissions from these or similar applications were considered to be responsible for the 33 x 10^6 fibres ℓ^{-1} reported in the top layer of melted snow in Ottawa (1).

TABLE 1

Asbestos Fibre Counts in Municipal Water Supplies

Location	Raw Water Source	Fibre Concentration ($\times 10^{-6}$ fibres ℓ^{-1})
Thunder Bay	Lake Superior	0.8
Niagara Falls	Niagara River	2.6
Englehart	Wells	1.6
Timmins	Mattagami River	1.8
Matachewan	Well	1.0
Leamington	Lake Erie	3.7
Amherstburg	Detroit River	5.1
Stoney Point	Lake St. Clair	23.9
Sarnia	Lake Huron	3.9
Grand Bend	Lake Huron	2.2
Windsor	Detroit River	18.2 - 25.3
Toronto	Lake Ontario	0.8 - 4.1

Data from Kay (2,3)

1:2 Study Program

Lawrence and Zimmermann (5) carried out bench scale studies investigating the removal of asbestos particles from water based on the hypothesis that asbestos, being a particulate contaminant in water, would react to conventional potable water pre-treatment processes (coagulation, flocculation and sedimentation) and filtration in a manner similar to other particulate matter. This in fact was shown to be the case. However, their experiments also pointed out that the usual parameter of effectiveness of the coagulation and filtration processes, namely turbidity, did not relate with any reliability to the asbestos particle content of the finished water at concentrations below 5 x 10^{10} fibres ℓ^{-1}. The next logical step was to test the bench scale results in a pilot scale water treatment facility with complete process control before moving to a full scale water treatment facility.

The present project was undertaken as a joint venture between the Ministry of the Environment, Ontario and the Canada Centre for Inland Waters, Department of Fisheries and Environment, Canada, to evaluate various pre-treatment and filtration processes for chrysotile asbestos fibre removal from potable water at the pilot plant scale.

The pilot plant study program at conception was basically a simple one in that a pilot plant unit incorporating coagulation, flocculation and sedimentation and various modes of filtration would be operated in such a way as to optimize turbidity removal and establish a baseline asbestos removal capacity for the system.

After the establishment of a baseline asbestos removal capacity, modifications would be carried out in order to observe any variance from the baseline in terms of asbestos removal. Ultimately the modifications which proved to be beneficial in terms of asbestos removal would be combined into one optimum process and thus effect maximum asbestos removal. Also it was planned to re-examine the turbidity - asbestos level correlation.

After the first series of runs was carried out, a problem emerged which was to plague the project and make following the study plan impossible. This problem was the difficulty encountered in the fortification of the raw water with sufficient asbestos to make removal measurement possible. Consequently, much of the effort was directed towards the problems involved in the tracing of asbestos when added to water rather than to the original study program.

2:0 METHODS

2:1 Pilot Plant Description

The pilot plant was set up in the Ministry of the Environment Research Test Facility in Toronto. Figure 1 shows the schematic of the treatment processes employed. Raw water was pumped at a rate of approximately 10 Igm (0.8 ℓ s^{-1}) from the Humber River into a 200 Ig (908 ℓ) surge tank with the excess flowing to waste. The water was then pumped at a rate of 5 Igm (0.4 ℓ s^{-1}) through a rotameter to a 840 Ig (3814 ℓ) asbestos contact chamber, giving a retention time of 2.8 hrs. A long shaft mixer kept the contents of the chamber well agitated at all times.

A metering pump added the asbestos suspension to the raw water in this chamber. Various mechanical systems were employed in the addition of the asbestos and will be discussed below. From the asbestos contact chamber, the raw water containing asbestos flowed by gravity to a flocculation chamber. A second chemical metering pump added sodium hypochlorite solution for pre-chlorination of the raw water-asbestos mixture as it left the asbestos contact chamber.

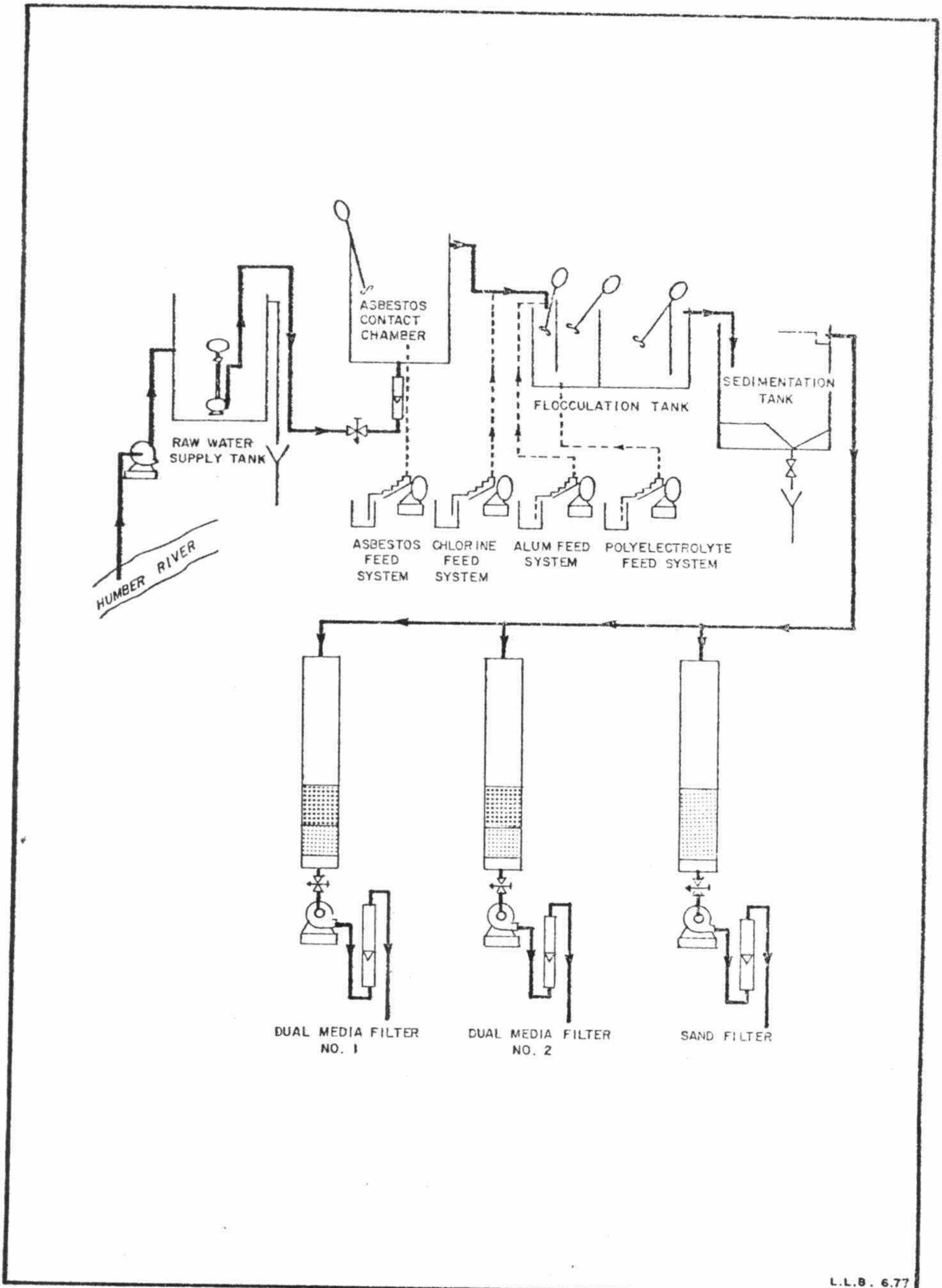


FIGURE 1: PILOT SCALE WATER TREATMENT PLANT

A primary coagulant (alum) was added to the chlorinated raw water-asbestos solution as it entered the rapid mix compartment of the flocculation tank. Two mixers gave an initial rapid mix. From the rapid mix compartment, the water flowed under a baffle into the first of two slow mix chambers. At the point where the water left the rapid mix compartment, a multiported tube was installed and a coagulant aid (activated silica) was added with a metering pump. The water flowed over a weir into the second slow mix chamber and then under another baffle to the outlet chamber. Both slow mix chambers were equipped with large propeller mixers travelling at approximately 50 RPM giving a G value of 20 sec^{-1}.

From the flocculation chamber, the water then flowed by gravity into a 900 Ig (4086 ℓ) sedimentation tank providing a retention time of 180 minutes. The water entered the sedimentation tank through a header, placed across the one end of the tank at mid-depth, and was taken off via a series of 6 launders near the surface at the other end of the sedimentation tank. The water left the sedimentation tank, entered another header system which fed three filter columns located below the flocculation-sedimentation equipment.

The filters consisted of 5½" (14 cm) ID acrylic columns, 8' (2.24 m) in height. Details of the media are given in Table 2.

Water was pumped through the filters with centrifugal pumps and the flow rate was controlled manually with throttling valves and monitored on rotameters. Flow was adjusted to 3 Igm/ft^2 (8.9 m h^{-1}) for each filter.

2:2 Chemical Dosage

The dosage and selection of primary coagulant and coagulant aid was determined by using a standard jar test procedure prior to each run. Coagulant aids were

TABLE 2

Filter Media in the Experimental Asbestos Removal Pilot Plant

Filter No.	Sand			Anthracite		
	Depth	Effective Size (mm)	Uniformity Coefficient	Depth	Effective Size (mm)	Uniformity Coefficient
Dual Media No. 1	8" (20.3 cm)	.45	1.5	16" (40.6 cm)	.9	1.7
Dual Media No. 2	8" (20.3 cm)	.45	1.5	16" (40.6 cm)	1.2	1.4
Sand	18" (45.7 cm)	.70	1.5	-	-	-

found to be necessary for good floc formation especially during the winter period, when low water temperatures were encountered. Generally, the dosage required for the Humber River raw water was in the range of 30 mg ℓ^{-1} alum plus 5 mg ℓ^{-1} activated silica. The initial dosage of chlorine was determined with a chlorine demand test, and the hypochlorite dosage was adjusted if necessary to maintain a free chlorine residual of 0.3 mg ℓ^{-1} throughout the system.

2:3 Pilot Plant Sampling

2:3:1 Sampling Locations

(1) Humber River Water - water sample taken in a 200 Ig (908 ℓ) surge tank prior to the water entering the asbestos contact chamber.

(2) Feed Water - water sample taken at the inflow to the flocculation chamber prior to coagulant addition and after asbestos and sodium hypochlorite have been added. At this sampling point, the asbestos and the Humber River water had been given approximately 3 hours of contact time.

(3) Post-Sedimentation Water - water sample taken from the collector box at the end of the launders in the sedimentation tank, just before the water enters the header for the filters.

(4) Dual Media Effluent 1 (DM-1) - the effluent of the dual media filter Number 1 containing 0.45 mm effective size (e.s.) sand and 0.9 mm e.s. anthracite.

(5) Dual Media Effluent 2 (DM-2) - the effluent of the dual media filter Number 2 containing 0.45 mm e.s. sand and 1.0 mm e.s. anthracite.

(6) Sand Filter Effluent - water taken from the effluent of the single media column containing 0.70 mm e.s. sand.

2:3:2 Pilot Plant Sampling Technique

The pilot plant was set up and monitored hourly over at least one retention period of the complete process. At the end of this period, intensive half-hourly monitoring was begun and when the turbidity of the effluent had reached a steady state, sampling was started. New 250 mℓ Nalgene bottles were rinsed 4 times in the water to be sampled, and filled with ¼ bottle portions at ½ hour intervals until the bottle was filled.

Based on past experiences, an estimation of the probable filter effluent sampling time was made and the Humber River water and feed water were sampled on a ¼ bottle portion method, taking into account the respective retention times of the system unit processes prior to the sampling of the filtered effluent and post-sedimentation samples. In this way, following steady state conditions, approximately the same "block" of water was sampled as it passed through the treatment system.

Any problems encountered in the run (e.g. turbidity breakthrough in one of the filters) during the sampling time, caused the sampling to be abandoned. In the example cited above, the filter would be backwashed; the Humber River and the feed water resampled and one system retention time later, the sampling would be resumed.

2:4 Asbestos Counting Technique

The asbestos counting for this project was carried out exclusively at the Canada Centre for Inland Waters. The counting was considered to be as precise as was possible considering the generally nebulous state-of-the-art: the reader should refer to Appendix I for further discussion of the analytical precision. On occasions when asbestos samples were re-examined because results were suspect, the original counts were generally confirmed. The analytical results in this project were considered to contain an uncertainty of a factor of 2 (Appendix II).

2:5 Asbestos Dosing System

Initial examination of the Humber River water indicated asbestos levels in the range of 5×10^5 fibres ℓ^{-1}. Hence, it was considered necessary to supplement the Humber River water to approach those higher raw asbestos water levels indicated in the 1972 Ontario survey.(2,3) For this purpose, a 50 mg ℓ^{-1} suspension of chrysotile asbestos, containing approximately 4.3×10^{12} fibres ℓ^{-1}, that had previously been developed and tested was procured (5).

The initial dosage method for the asbestos consisted of agitating the asbestos "suspension" (50 mg ℓ^{-1} asbestos) with an ultrasonic blender for 30 minutes and then diluting this "suspension" with distilled water (1-100 dilution) in a polyethylene drum fitted with a mechanical mixer and an ultrasonic probe. The diluted asbestos suspension was then fed, via a metering pump, at a rate of 0.792 ℓ h^{-1} over the top of the asbestos contact chamber and down to about mid-depth in the chamber.

The final dosage method consisted of feeding the pure asbestos suspension directly into the side of the contact chamber from a 1 ℓ feed vessel equipped with an ultrasonic blender. The discharge line from the metering pump was shortened to 6" (15 cm) and the effluent tubing size was reduced by half. The intermediate steps carried out to arrive at this final system are outlined in Appendix II.

2:5:1 Point Source Study

In an attempt to discover the fate of the fibres introduced into the pilot plant, samples were withdrawn for analysis at various states of the process. Samples were withdrawn from; a) the asbestos suspension in the feed vessel, b) the asbestos suspension immediately after entering the contact chamber, c) top, d) middle, e) bottom of contact chamber and f) inflow to flocculation chamber.

3:0 RESULTS & DISCUSSION

3:1 Asbestos Dosing

3:1:1 Full Scale Runs

As noted in the methods section, a continuing effort was made throughout this study to improve the asbestos feeding system in the pilot plant. The mechanical modifications and the expected and observed asbestos levels are presented in Appendix II.

Examination of the results presented in Appendix II in terms of the factor of 2 shows that not only did the observed fibre counts in the feed water not approach the numerical value anticipated, but were low by a factor greater than 2 in 66% of the cases.

In a study carried out recently by the Ontario Research Foundation (6) in which lake water was spiked with chrysotile asbestos suspension, the counts after dilution were outside the range allowed by applying a factor of 2 to the anticipated concentration approximately 47% of the time. Allowing that this was a bench scale experiment using relatively turbidity-free water, the fact that the results of the pilot plant work carried out in this project were outside of the anticipated range 66% of the time does not seem to be unreasonable.

3:1:2 Point Source Study

The results of the point source study are presented in Table 4. Clearly, the asbestos is entering the con-

Table 3

Concentrations of Fibres at Various Locations Throughout the Pilot Plant

Location	Concentration (fibres ℓ^{-1})	Anticipated Concentration (fibres ℓ^{-1})
Asbestos Suspension Vessel	6.6×10^{11}	4×10^{11}
Feed pipe at Contact Chamber	6.6×10^{11}	4×10^{11}
Contact Chamber (top)	1.2×10^{6}	4×10^{7}
Contact Chamber (middle)	2.4×10^{6}	4×10^{7}
Contact Chamber (bottom)	too turbid to measure	4×10^{7}
Flocculation Chamber	1.0×10^{6}	4×10^{7}

tact chamber but is either settling to the bottom where it cannot be detected due to high turbidity (turbidity levels greater than 35 Ftu prohibit examination for asbestos fibres) or it is adhering to the clarifier walls. Since water in the contact chamber was subjected to vigorous agitation and was flowing upwards, settling of the asbestos to the bottom must be considered as only a remote possibility. There was some turbidity buildup in the bottom of the asbestos contact chamber, but relative to the amount of turbid water passing through the system (5 Ig min.$^{-1}$ (0.4 ℓ sec^{-1})), it was considered minimal. The turbidity readings on the water passing through the contact chamber were virtually equal upstream and downstream of the chamber. No visible asbestos deposits could be detected on the chamber walls, but with the small quantities involved, this was perhaps not surprising. Consequently, we were not able to conclusively determine the ultimate fate of the asbestos except that it appeared to enter but not leave the contact chamber.

3:1:3 Asbestos Suspension

A thorough re-examination of the fibre counts of the 50 mg ℓ^{-1} asbestos suspension carried out after Runs #2,3 and 4 became available after the fifth run had been carried out (Appendix II). The asbestos feed suspension which was initially determined to contain 4.3×10^{12} fibres ℓ^{-1} was found to have only 4.6×10^{11} fibres ℓ^{-1}. This tended to shed a different light on the results obtained in the Runs #2,3 and 4 and the subsequent doubling of dosing rate and concentration (Appendix II) in that the expected levels were reduced by one order of magnitude. In fact, using the 4.6×10^{11} fibre ℓ^{-1} concentration in the asbestos suspension, the asbestos fibre levels in Runs #2 and 3 exceeded the expected levels. Nevertheless, Run #3 and the two subsequent calibration runs in which the dosage and concentration were doubled showed fibre counts well below the levels anticipated even for the 4.6 x 10^{11} fibre ℓ^{-1} concentration in the concentrated suspension. Numerous checks during the remainder of the feeding experiments indicated only one occasion when the fibre count of the 50 mg ℓ^{-1} asbestos suspension varied significantly from 4 x 10^{11} fibres ℓ^{-1}. On that occasion (a count of 2 x 10^9 fibre ℓ^{-1} was determined) the run was deleted and is not reported above. Also, the suspension that remained in the asbestos feed vessel after the pilot plant run was examined on two occasions and exhibited the same 4 x 10^{11} fibre ℓ^{-1} level as determined in the suspension following make-up.

3:2 Pilot Plant Runs

The results of the asbestos counts and turbidity measurements for the pilot plant runs are presented in Table 3, and in Appendix III. Numerous other runs were carried through to completion only to find that the asbestos levels in the feed water were not sufficient to justify counting of post-sedimentation and post-filtration samples. This problem is documented above.

Examination of the pilot plant data presented in Table 3 leads to certain general observations. However, these observations must be approached with caution for many reasons including: the present state-of-the-art in asbestos counting technology, the experimental problems encountered in the feeding and retrieval of the asbestos and also the relatively small number of data obtained. With these qualifications in mind, the observations are presented below.

In three of the six post-sedimentation samples reported in Table 3, there was a significant reduction in the asbestos fibre counts corresponding to reductions in turbidity levels from those levels encountered in the feed water. This would have been expected based

TABLE 4 ASBESTOS REMOVAL PILOT PLANT DATA

					Filters		
Run #	Alum [1]	Act. Si [1]	Feed Water *	Post Sed. *	DM-1*	DM-2*	Sand*
2	30	5	4.02 (16 Ftu)	1.5 (4.1 Ftu)	0.31 (0.7 Ftu)	0.3 (0.7 Ftu)	0.73 (1.8 Ftu)
3	24	3	0.81 (25 Ftu)	- (5 Ftu)	0.23 (0.3 Ftu)	0.24 (0.3 Ftu)	0.56 (1.2 Ftu)
4	36	6	7.8 (20 Ftu)	1.4 (5.1 Ftu)	0.07 (0.15 Ftu)	< 0.05 (0.16 Ftu)	0.06 (0.13 Ftu)
12	30	5	17 (22 Ftu)	17.0 (4 Ftu)	0.14 (0.14 Ftu)	0.8 (0.15 Ftu)	0.3 (0.18 Ftu)
13	30	5	2.3 (8 Ftu)	5.4 (3.0 Ftu)	1.6 (0.11 Ftu)	< 0.05 (0.10 Ftu)	1.9 (0.15 Ftu)
14	30	5	3.4 (20 Ftu)	0.8 (4.8 Ftu)	< 0.5 (0.14 Ftu)	< 0.5 (0.15 Ftu)	< 0.5 (0.16 Ftu)
15	30	5	6.9 (28 Ftu)	1.4 (5.3 Ftu)	< 0.05 (0.16 Ftu)	< 0.05 (0.16 Ftu)	< 0.05 (0.16 Ftu)

[1] Alum and activated silica dosage in mg ℓ^{-1}

* Asbestos results in millions of fibres per litre

on the work of Lawrence and Zimmermann (5) who found that bench scale studies of conventional potable water pre-treatment processes did, in fact, produce a substantial reduction in the chrysotile asbestos concentrations in potable water. Similar observations were made regarding the reaction of other asbestos species to conventional potable water treatment processes in work carried out by the U.S. Environmental Protection Agency (7). However, the fact that three of the six post-sedimentation samples reported exhibited asbestos counts that were not significantly different from those encountered in the feed water makes any generalization difficult.

Filtration in the majority of cases significantly reduced the amount of asbestos in the water from that which was encountered in the post-sedimentation sample. In the pilot plant study, the reported fibre concentrations in the finished water were below 1 x 10^6 fibres ℓ^{-1} in 90% of the cases and below 5 x 10^5 fibres ℓ^{-1} in 76% of cases.

The dual media filters produced an effluent that was superior to the sand filter effluent in terms of turbidity. The removal of turbidity through the two dual media filters was virtually equal over the duration of the study. As may have been expected, the actual asbestos fibre counts also reflected the superiority of the dual media filters. However, when the asbestos counts were subjected to the scrutiny of the uncertainty factor of 2 (Appendix III), there was no significant difference noted between the asbestos fibre concentrations in the three filter effluents.

In the majority of the data available in Table 3, the lowering of the turbidity level across the process generally coincided with the lowering of the asbestos counts, although the data are so limited and qualified as to make any attempt to index turbidity and asbestos, even for this specific raw water, unjustified.

From Table 3, there is no obvious relationship between the initial and final asbestos fibre concentrations across the process. Relatively low asbestos fibre concentrations in the feed water did not always produce a correspondingly lower fibre concentration in the effluent. Conversely, high fibre levels in the feed water often corresponded to low fibre concentrations in the filter effluent.

3:2:1 Initial Results

In the first series (Runs #2, 3 & 4) the Runs #2 and 4 showed considerable promise in that there was a significant decrease in asbestos levels corresponding to decreases in turbidity as the water proceeded through the treatment process. However, the results in Run #3 contradicted these results with the asbestos being virtually the same throughout the process while the turbidity levels exhibited decreases across the system similar to those noted in Runs #2 and #4. The problem encountered in the addition of the asbestos into the raw water was evident here with Runs #2 and #4 exhibiting asbestos levels in the feed water, one order of magnitude below that which was expected. Run #3 showed feed water asbestos levels two orders of magnitude lower than expected. The extremely low level of asbestos encountered in the feed water in Run #3 possibly accounts for the erratic results.

3:2:2 Results Following Asbestos Feed System Modification

The asbestos counts on the next series of runs (Runs #12 and #13) exhibited even more erratic behavior. In Run #12 the theoretical feed dosage of 33×10^6 asbestos fibres ℓ^{-1} averaged 17×10^6 asbestos fibres ℓ^{-1} according to the actual counts on the feed water samples.

Although the turbidity level dropped from 22 Ftu in the feed water to 4 Ftu in the post-sedimentation sample, the asbestos count remained unchanged. The asbestos levels in the filter effluent were generally low, with the lowest turbidity corresponding with the lowest asbestos count. No significant difference was observed between the asbestos counts in the other two effluent samples and hence correlation with turbidity was not possible.

Run #13 was carried out at a time when the Humber River water turbidity was much lower than that encountered in the other runs (8 Ftu in Run #13 as compared with 16 to 28 Ftu in the other runs). No significant change in the asbestos levels was noted from the feed water sample to the post-sedimentation sample even though a drop in turbidity from 8 Ftu to 3 Ftu was noted for the corresponding samples. The actual counts showed an increase from an average of 2.3×10^6 fibres ℓ^{-1} in the feed water to 5.4×10^6 fibres ℓ^{-1} in the post-sedimentation sample. The three post-filtration asbestos counts exhibited erratic behavior. The lowest asbestos count corresponded to the lowest turbidity level (DM-2). However, the asbestos counts in the other two finished water samples were not significantly different from those encountered in the feed water; at the same time, the turbidities only varied 0.01 and 0.04 Ftu from that exhibited by the DM-2 filter effluent. Again, it must be emphasized that the feed water asbestos levels were 1 order of magnitude lower than the theoretical dosage of asbestos. It may have been expected that the lower turbidity in the feed water in Run #13 would have led to greater asbestos counts in the feed water, but the opposite was the case.

Run #14 exhibited a significant decrease in asbestos fibres during the pre-treatment process, but an insignificant decrease in fibre concentration was noted between the post-sedimentation and all three post-filtration samples.

Run #15 exhibited the behavior that might have been expected; a decrease in asbestos counts being noted after sedimentation and a further decrease following filtration. Although this run did appear to be successful, the enigma of the asbestos that was theoretically being fed into the system (64×10^6 fibres ℓ^{-1} in Run #15) showing an asbestos count of only 6.9×10^6 fibres ℓ^{-1} in the feed water must affect the interpretation of all other results obtained.

4:0 CONCLUSIONS

(1) The parameter examined in this series of experiments is of a nature such that accurate analytical determination is often not possible.

(2) Consistent quantitative analysis of chrysotile asbestos fibres in river water following dilution of a concentrated chrysotile asbestos suspension could not be obtained. Generally, the counts obtained after dilution ranged from the anticipated concentration to one or two orders of magnitude below the anticipated concentration.

(3) A subjective analysis of the pilot plant results indicates that optimized conventional treatment can significantly reduce asbestos levels in potable water. It is felt that objective predictions and/or conclusions as to treatment efficiency are presently impossible given the current state-of-the-art in counting technology.

(4) No direct relationship between fibre concentration and turbidity was established although in many instances low fibre concentration was associated with low turbidity.

5:0 RECOMMENDATIONS

(1) That further asbestos removal studies be curtailed until an accurate standard analytical asbestos counting method is developed.

(2) Given (1) above, that further studies be pursued under pilot plant conditions in an area with a significant asbestos concentration in the raw water.

6:0 References

(1) Cunningham, H.M., and Pontefract, R., "Asbestos Fibres in Beverages and Drinking Water." Nature, Vol. 232: 332-333, 1971.

(2) Kay, G., "Ontario Intensifies Search for Asbestos in Drinking Water", Journal of Water and Pollution Control, September 1973, 33-35.

(3) Kay, G., As reported in"Asbestos in the Great Lakes Basin with Emphasis on Lake Superior". A report to the International Joint Commission, Windsor, Ontario. (1975).

(4) Ontario Ministry of the Environment, Water Technology Section. Unpublished Data.

(5) Lawrence, J., and Zimmermann, H.W., "Potable Water Treatment for some Asbestiform Minerals: Optimization and Turbidity Data", Water Research, Vol. 10, pp. 195-198 1976 .

(6) Ontario Research Foundation "Improved Methodology for Determination of Asbestos as a Water Pollutant", Performed under contract for Canada Centre for Inland Waters, Burlington, Ontario. (1976).

(7) Black and Veatch, Consulting Engineers, Kansas City, Missouri, U.S.A. 64114. "Direct Filtration of Lake Superior Water for Asbestiform Fibre Removal", EPA 670/2-75-050, June 1975.

(8) Durham, R.W., and Pang, T.W.S., "Asbestos Fibres in Lake Superior", Amer. Soc. Testing Materials, Special Publication. No. 573 pp. 5-13, 1975 .

(9) Ontario Ministry of the Environment, "An Inter-laboratory Study of Asbestiform Mineral Fibre Levels in the Water Supply of Thunder Bay, Ontario", 1975

Appendix I

Analytical Techniques for Asbestos Fibres in Water

The sample preparation and counting procedures used for this project are those previously described by Durham and Pang (1). A 250 ml sample was centrifuged at 20,000 rev. min^{-1} (30,000 g) for 2 hours and the separated fibres ultrasonically resuspended in 1 ml distilled water. One micro-litre of this suspension was then transferred to a 3 mm^2 carbon coated grid, dried and the fibres counted under a Siemens 101 transmission electron microscope (x 20,000 magnification). When the concentration of fibres was low (10^5 - 10^6 ℓ^{-1}), it was necessary to count all of the approximately 100 grid openings covered by the 1 $\mu\ell$ drop. At higher concentrations, it was sufficient to count only 20-50 squares and assume that these squares were representative of the entire drop. Background counts were carried out on each grid before use and this number subtracted from the total number of fibres counted for the sample. The limit of detectability was 5 x 10^4 fibres ℓ^{-1}. For further details, the reader should consult the original reference by Durham & Pang (1).

Specimen Calculation

Experimental observation	-	60 fibres in 50 squares
Background count	-	15 fibres in 100 squares

This is equivalent to 120 fibres in 100 squares (approximate coverage of a 1 $\mu\ell$ drop).

Less background = 105 fibres in 100 squares

Since fibres cannot be observed on the grid bars, a factor of 2.36 is introduced (derived from calculation of the ratio of holes in the grid to the total area).

1 $\mu\ell$ of concentrated suspension contains

$105 \times 2.36 = 248$ fibres

1 ml of suspension (all fibres from 250 ml of sample) contains

248×10^3 fibres

1 litre of original sample contained

$248 \times 10^3 \times 4 = 9.92 \times 10^5$ fibres

Sample preparation techniques do differ from one laboratory to another (eg. centrifuging, filtering with subsequent ashing of the filter media or filtering and removing the media with organic solvent in a condensation washer) and at the present time, no one technique has been accepted as the standard. At the time of commencing this project, Durham and Pang (1) claimed the precision of the analytical method was about ± 15% but more recent studies and interlaboratory comparisons have necessitated a re-assessment of this value. In 1975, the Ontario Ministry of the Environment arranged for several split samples to be analysed at three independent Ontario Laboratories; discrepancies for any given sample varied by up to two orders of magnitude with complete disagreement on the type of asbestos fibres present (2). An Asbestos Methodology Committee, sponsored by the Ontario Ministry of the Environment, is currently evaluating and assessing the various analytical techniques and hopefully a standard procedure will be formulated in the near future. In view of the recent work by the Ontario Research Foundation (3), it was felt that the best analytical results obtained during the current project contained an overall uncertainty of at least a factor of 2 (i.e. a sample reported at 1×10^6 fibres ℓ^{-1} could have values from 5×10^5 fibres ℓ^{-1} to 2×10^6 fibres ℓ^{-1}).

References

(1) Durham, R.W., and Pang, T.W.S., "Asbestos Fibres in Lake Superior", Amer. Soc. Testing Materials, Special Publication. No. 573, pp. 5-13, 1975 .

(2) Ontario Ministry of the Environment, "An Interlaboratory Study of Asbestiform Mineral Fibre Levels in the Water Supply of Thunder Bay, Ontario", 1975

(3) Ontario Research Foundation, "Improved Methodology for Determination of Asbestos as a Water Pollutant", Performed under contract for Canada Centre for Inland Waters, Burlington, Ontario, (1976).

APPENDIX II

Asbestos Feeding System

The initial asbestos feeding system produced asbestos counts in the feed water of 4.02, 0.8 and 7.8 x 10^6 fibres ℓ^{-1} instead of the 25 x 10^6 fibres ℓ^{-1} expected (Runs 2,3,4).

Doubling the feed rate of the asbestos suspension or doubling the concentration of the asbestos suspension produced asbestos counts in the feed water of 1.0 x 10^6 and 1.4 x 10^6 fibres ℓ^{-1} respectively, instead of the 50 x 10^6 fibres ℓ^{-1} expected.

This failure to deliver the theoretical asbestos levels in the feed water led to the assumption that the problem was in the long vertical line leading from the metering pump over the top of the asbestos contact chamber. Hence, a port was installed at mid-depth in the chamber and the diluted suspension was fed directly into the side of the asbestos contact chamber just above the inlet. This modification rendered counts of 0.4 x 10^6 and 4.3 x 10^6 asbestos fibres ℓ^{-1} in the feed water.

The next modification carried out was to omit any dilution of the asbestos suspension and feed it directly into the asbestos contact chamber. An ultrasonic blender was installed in the asbestos feed vessel to effect mixing. A finer metering pump was installed and a feed rate of 0.06 ℓ h^{-1} was adopted in order to render a 20 x 10^6 asbestos fibre ℓ^{-1} level in the feed water. This system produced feed water with counts of 2.3 x 10^6, 4.3 x 10^6 and 0.9 x 10^6 asbestos fibres ℓ^{-1}.

Subsequently, the dosage was increased to 0.1 ℓ h^{-1} (theoretical anticipated dosage of 33 x 10^6 fibres ℓ^{-1}) from the previous 0.06 ℓ h^{-1} and feed water levels of 23 x 10^6, 6.2 x 10^6, 1.6 x 10^6 and 2.2 x 10^6 fibres ℓ^{-1} were obtained. A further modification involving the reduction in the size of the effluent tubing from the metering pump to the asbestos contact chamber gave somewhat encouraging results of 11 x 10^6 and 12 x 10^6 fibres ℓ^{-1} in the feed water. At this point, two further full scale pilot plant runs were carried out (Runs #12 and #13 reported above). The feed water asbestos count in Run #12 ranged from 11 x 10^6 to 24 x 10^6 fibres ℓ^{-1} with a mean of 17 x 10^6 fibres ℓ^{-1}. This was considerably below the 33 x 10^6 fibres ℓ^{-1} expected but at least in the anticipated range. The next run using the same system and the same batch of asbestos suspension produced levels in the feed water ranging from 0.8 x 10^6 to 3.2 x 10^6 fibres ℓ^{-1} giving a mean of 2.3 x 10^6 fibres ℓ^{-1}. Two subsequent tests were carried out and again rendered only 1.6 x 10^6 and 1.4 x 10^6 fibres ℓ^{-1} in the feed water.

At this point the only possible loss of asbestos which could be in the feeding system was assumed to be in the 18" (46 cm) of tubing leading from the metering pump into the asbestos contact chamber. Consequently, the metering pump was installed on the side of the asbestos contact chamber reducing the length of the discharge tubing to approximately 6" (15 cm). The feeding rate of the asbestos suspension was maintained at 0.1 ℓ h^{-1}. This modification rendered asbestos levels in the feed water of 3.4 x 10^6 and 1.0 x 10^6 fibres ℓ^{-1}. Finally, a run was carried out doubling the feed rate to 0.2 ℓ h^{-1} and using the close coupled system noted above. This produced a level in the feed water of 6.9 x 10^6 fibres ℓ^{-1} while the theroetical amount that should have been present was 66 x 10^6 fibres ℓ^{-1}.

APPENDIX II

A Comparison of Actual and Expected Fibre Concentrations in the Pilot Plant Asbestos Feeding Experiments Given a Factor of 2 in the Counting of the Asbestos

	Feed System	Expected Fibre Concentration (fibres ℓ^{-1} x 10^6)		Resultant Fibre Concentration (fibre ℓ^{-1} x 10^6)		Results within Expected Range
		Count	Range	Count	Range	
1.	original feed susp. ,13.2 ml/min. of 1% soln of 4.3 x 10^{13} fibres ℓ^{-1} suspension	25	12.5 - 50	4.02	2.01-8.04	No
2.	"	25	12.5 - 50	0.8	0.4 -1.6	No
3.	"	25	12.5 - 50	7.8	3.9 -15.6	Yes
4.	26.4 ml/min. of 1% susp. of 4.3 x 10^{12} fibres ℓ^{-1} suspension	50	25 - 100	1.0	0.5 - 2.0	No
5.	13.2 ml/min. of 2% susp. of 4.3 x 10^{12} fibres ℓ^{-1} suspension	50	25 - 100	1.4	0.7 - 2.8	No
6.	(1) above using suspension count of 4.6 x 10^{11} fibres ℓ^{-1}	2.5	1.25 - 5	4.02	2.01-8.04	Yes
7.	(2) above using suspension count of 4.6 x 10^{11} fibres ℓ^{-1}	2.5	1.25 - 5	0.8	0.4 -1.6	Yes
8.	(3) above using suspension count of 4.6 x 10^{11} fibres ℓ^{-1}	2.5	1.25 - 5	7.8	3.9 -15.6	Yes

	Feed System	Expected Fibre Concentration (fibre ℓ^{-1} x 10^{6})		Resultant Fibre Concentration (fibre ℓ^{-1} x 10^{6})		Results within Expected Range
		Count	Range	Count	Range	
9.	(4) above using suspension count of 4.6 x 10^{11}	5.0	2.5 - 10	1.0	0.5 - 2.0	No
10.	(5) above using suspension count of 4.6 x 10^{11}	5.0	2.5 - 10	1.4	0.7 - 2.8	Yes
11.	13.2 ml/min. of 1% susp. of 4.6 x 10^{11} fibres ℓ^{-1} suspension-mid-chamber port installed	25	12.5 - 50	0.4	0.2 - 0.8	No
12.	"	25	12.5 - 50	4.3	2.15 - 8.6	No
13.	1 ml/min. of 100% susp. of 4.6 x 10^{11} fibre ℓ^{-1} suspension	20	10 - 40	2.3	1.15 - 4.6	No
14.	"	20	10 - 40	4.3	2.15 - 8.6	No
15.	"	20	10 - 40	0.9	0.45 - 1.8	No
16.	1.67 ml/min of 100% susp. of 4.6 x 10^{11} fibre ℓ^{-1} suspension	33	16.5 - 66	23	11.5 - 46	Yes
17.	"	33	16.5 - 66	6.2	3.1 - 12.4	No
18.	"	33	16.5 - 66	1.6	0.8 - 3.2	No
19.	"	33	16.5 - 66	2.2	1.1 - 4.4	No
20.	as above but with reduction in size of tubing from metering pump to contact chamber	33	16.5 - 66	11	5.5 - 22	Yes

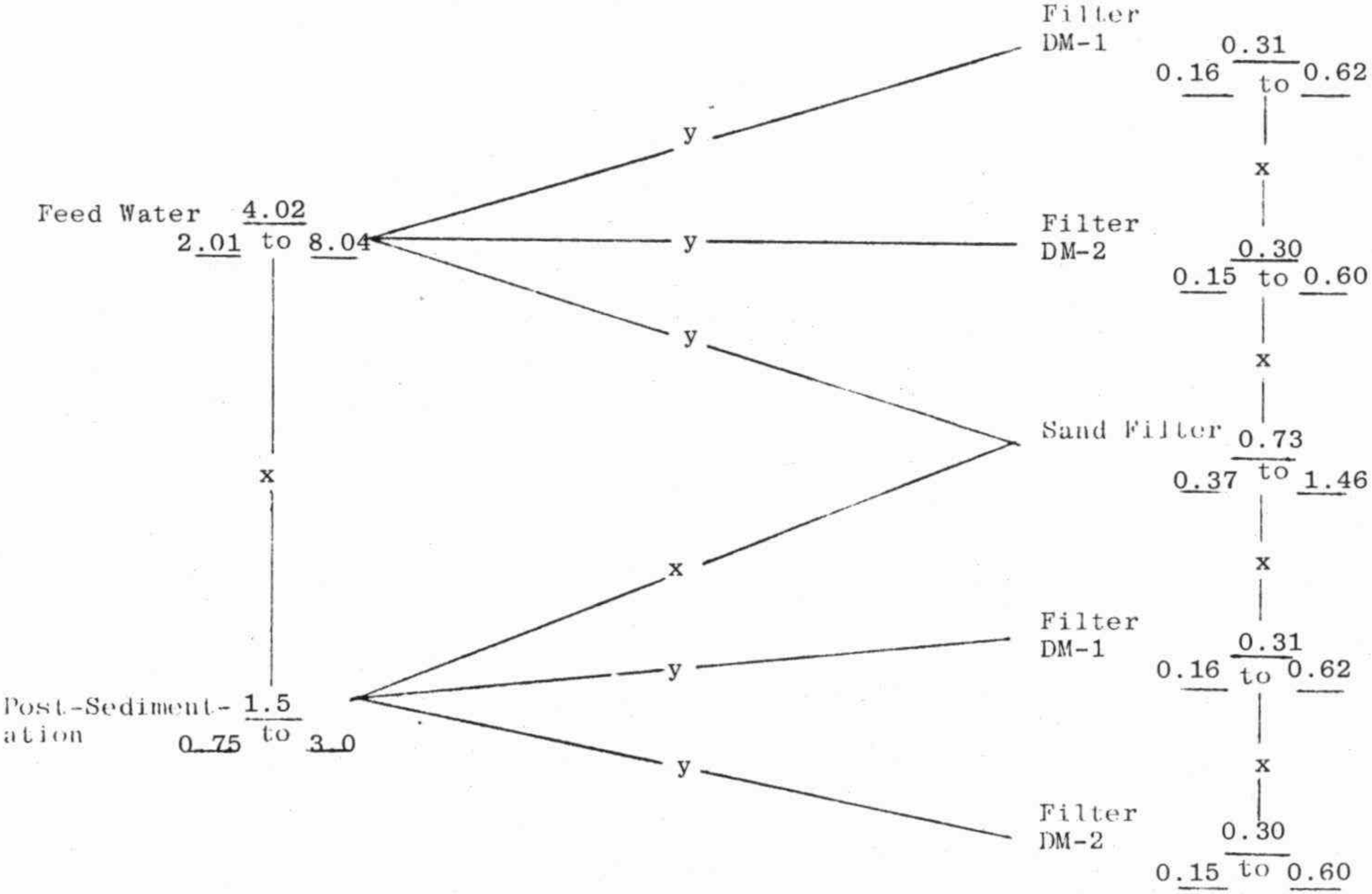
Feed System	Expected Fibre Concentration (fibre $\ell^{-1} \times 10^6$)		Resultant Fibre Concentration (fibre $\ell^{-1} \times 10^6$)		Results within Expected Range
	Count	Range	Count	Range	
21. as above but with reduction in size of tubing from metering pump to contact chamber	33	16.5 - 66	12	6 - 24	Yes
22. "	33	16.5 - 66	11	5.5 - 22	Yes
23. "	33	16.5 - 66	24	12 - 48	Yes
24. "	33	16.5 - 66	17	8.5 - 34	Yes
25. "	33	16.5 - 66	0.8	0.4 - 1.6	No
26. "	33	16.5 - 66	3.2	1.6 - 6.4	No
27. "	33	16.5 - 66	2.3	1.15 - 4.6	No
28. "	33	16.5 - 66	1.6	0.8 - 3.2	No
29. "	33	16.5 - 66	1.4	0.7 - 2.8	No
30. as above but shortening effluent line from metering pump to contact chamber	33	16.5 - 66	3.4	1.7 - 6.8	No
31. "	33	16.5 - 66	1.0	0.5 - 2.0	No
32. 3.3ml/min. of 100% 4.6×10^{11} fibres ℓ^{-1} suspension	64	32 - 128	6.9	3.45 - 13.8	No

APPENDIX III

Pilot Plant Asbestos Results in Terms of the Counting Uncertainty Factor of 2

MOE/CCIW PILOT PLANT STUDY
ASBESTOS FIBRE COUNTS * AND
THEIR SIGNIFICANCE, GIVEN A
UNCERTAINTY FACTOR OF 2

Run #2



Notes

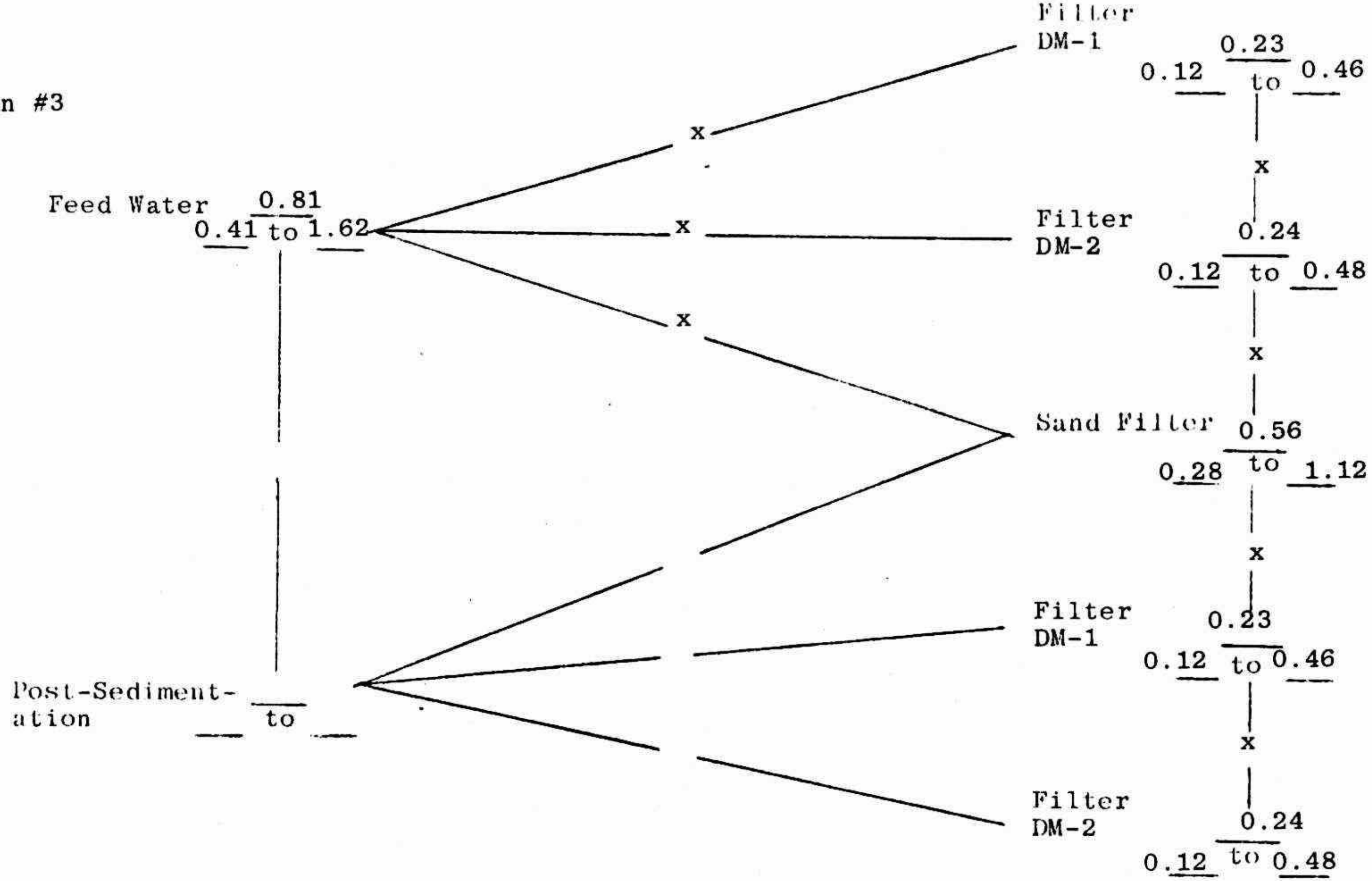
"x" denotes that no significant difference exists between the two asbestos counts given the range dictated by the factor of 2.

"y" denotes that a significant difference exists between the two asbestos counts given the range dictated by the factor of 2.

* all asbestos counts are given in fibres $\ell^{-1} \times 10^6$

MOE/CCIW PILOT PLANT STUDY
ASBESTOS FIBRE COUNTS * AND
THEIR SIGNIFICANCE, GIVEN A
UNCERTAINTY FACTOR OF 2

Run #3



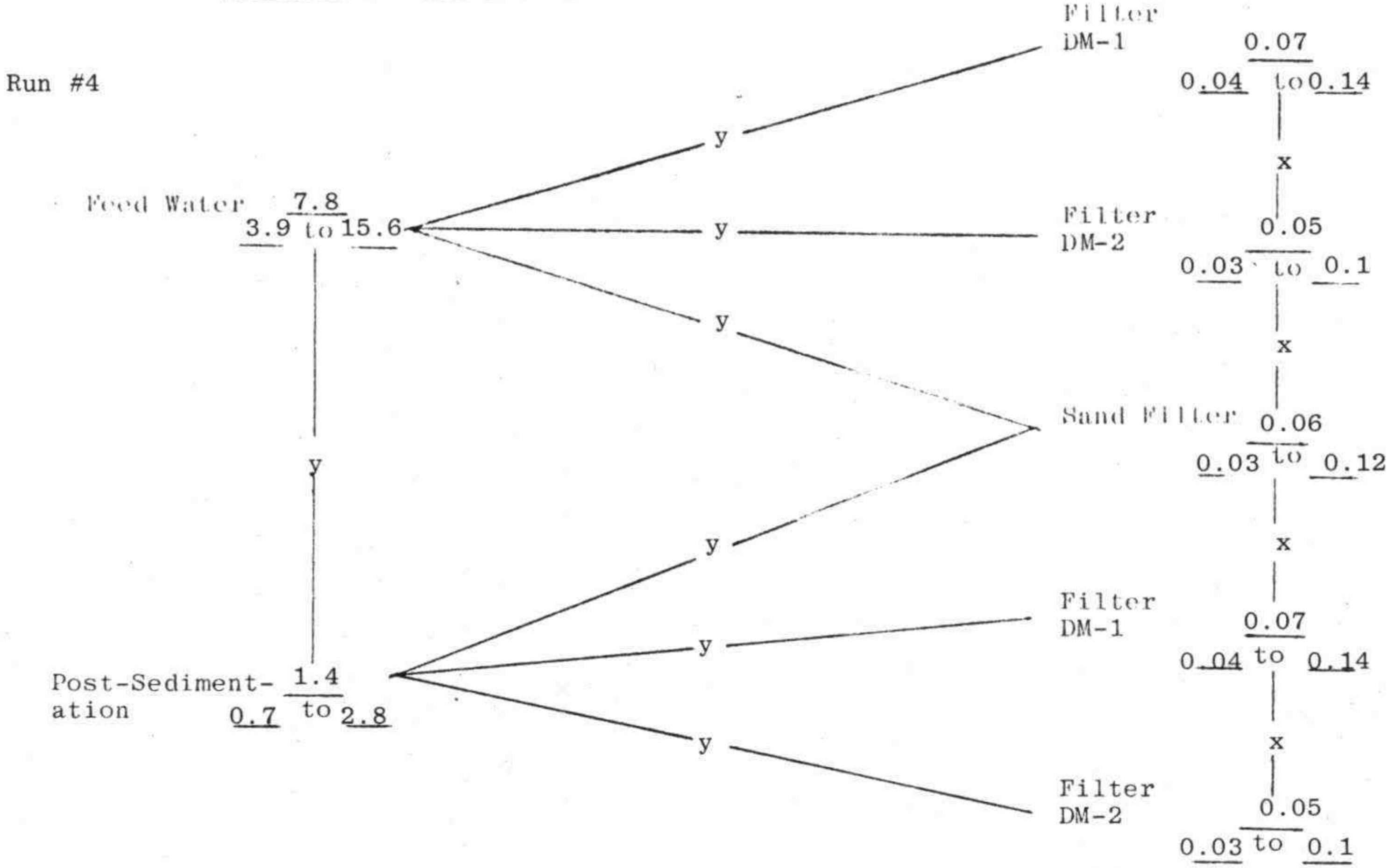
Notes

"x" denotes that no significant difference exists between the two asbestos counts given the range dictated by the factor of 2.

"y" denotes that a significant difference exists between the two asbestos counts given the range dictated by the factor of 2.

* all asbestos counts are given in fibres $\ell^{-1} \times 10^6$

MOE/CCIW PILOT PLANT STUDY
ASBESTOS FIBRE COUNTS * AND
THEIR SIGNIFICANCE, GIVEN A
UNCERTAINTY FACTOR OF 2



Notes

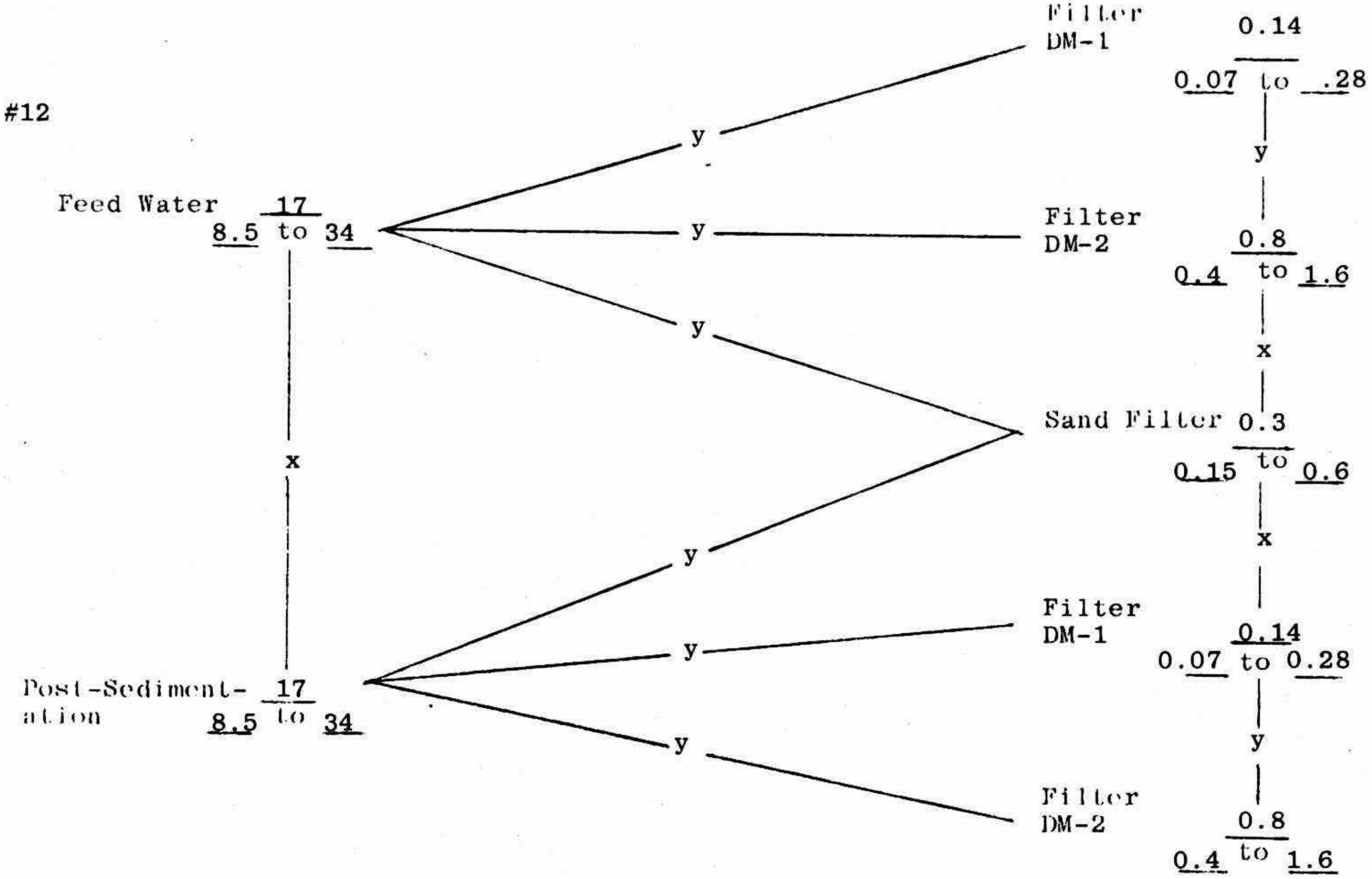
"x" denotes that no significant difference exists between the two asbestos counts given the range dictated by the factor of 2.

"y" denotes that a significant difference exists between the two asbestos counts given the range dictated by the factor of 2.

* all asbestos counts are given in fibres $\ell^{-1} \times 10^6$

MOE/CCIW PILOT PLANT STUDY ASBESTOS FIBRE COUNTS * AND THEIR SIGNIFICANCE, GIVEN A UNCERTAINTY FACTOR OF 2

Run #12

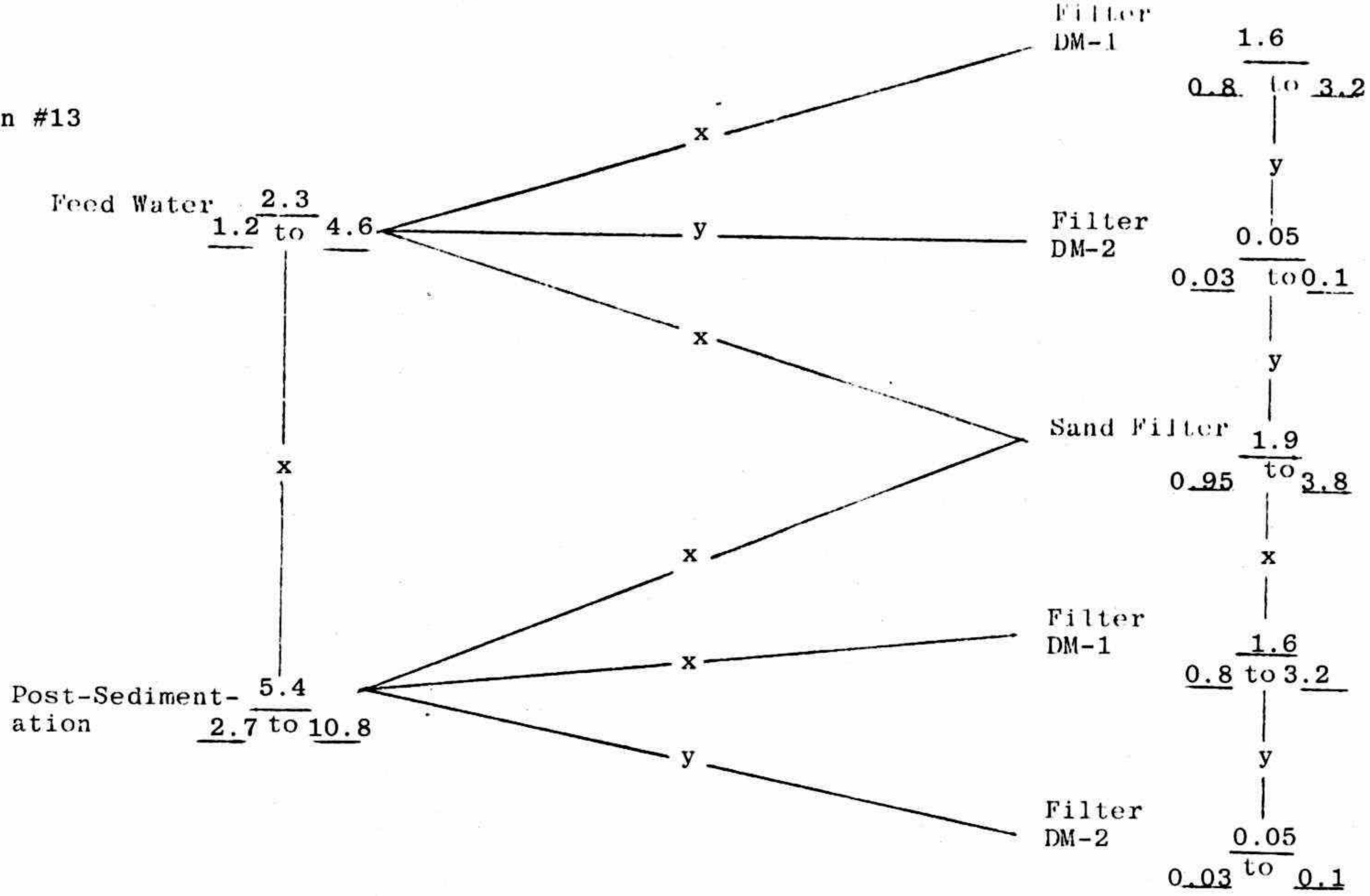


Notes

"x"	denotes that no significant difference exists between the two asbestos counts given the range dictated by the factor of 2.
"y"	denotes that a significant difference exists between the two asbestos counts given the range dictated by the factor of 2.
*	all asbestos counts are given in fibres $\ell^{-1} \times 10^6$

MOE/CCIW PILOT PLANT STUDY
ASBESTOS FIBRE COUNTS * AND
THEIR SIGNIFICANCE, GIVEN A
UNCERTAINTY FACTOR OF 2

Run #13



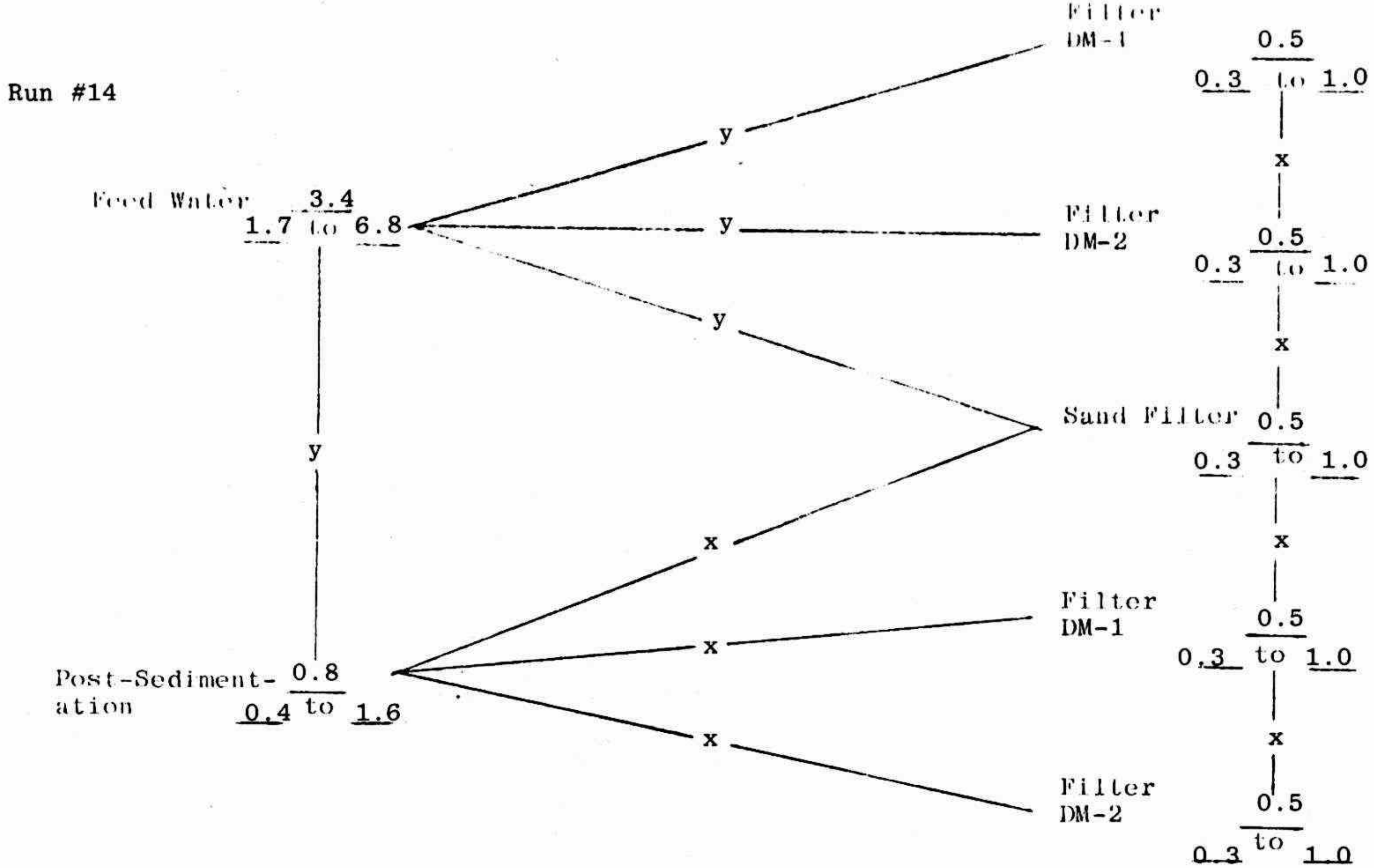
Notes

"x" denotes that no significant difference exists between the two asbestos counts given the range dictated by the factor of 2.

"y" denotes that a significant difference exists between the two asbestos counts given the range dictated by the factor of 2.

* all asbestos counts are given in fibres $\ell^{-1} \times 10^6$

MOE/CCIW PILOT PLANT STUDY
ASBESTOS FIBRE COUNTS * AND
THEIR SIGNIFICANCE, GIVEN A
UNCERTAINTY FACTOR OF 2



Notes

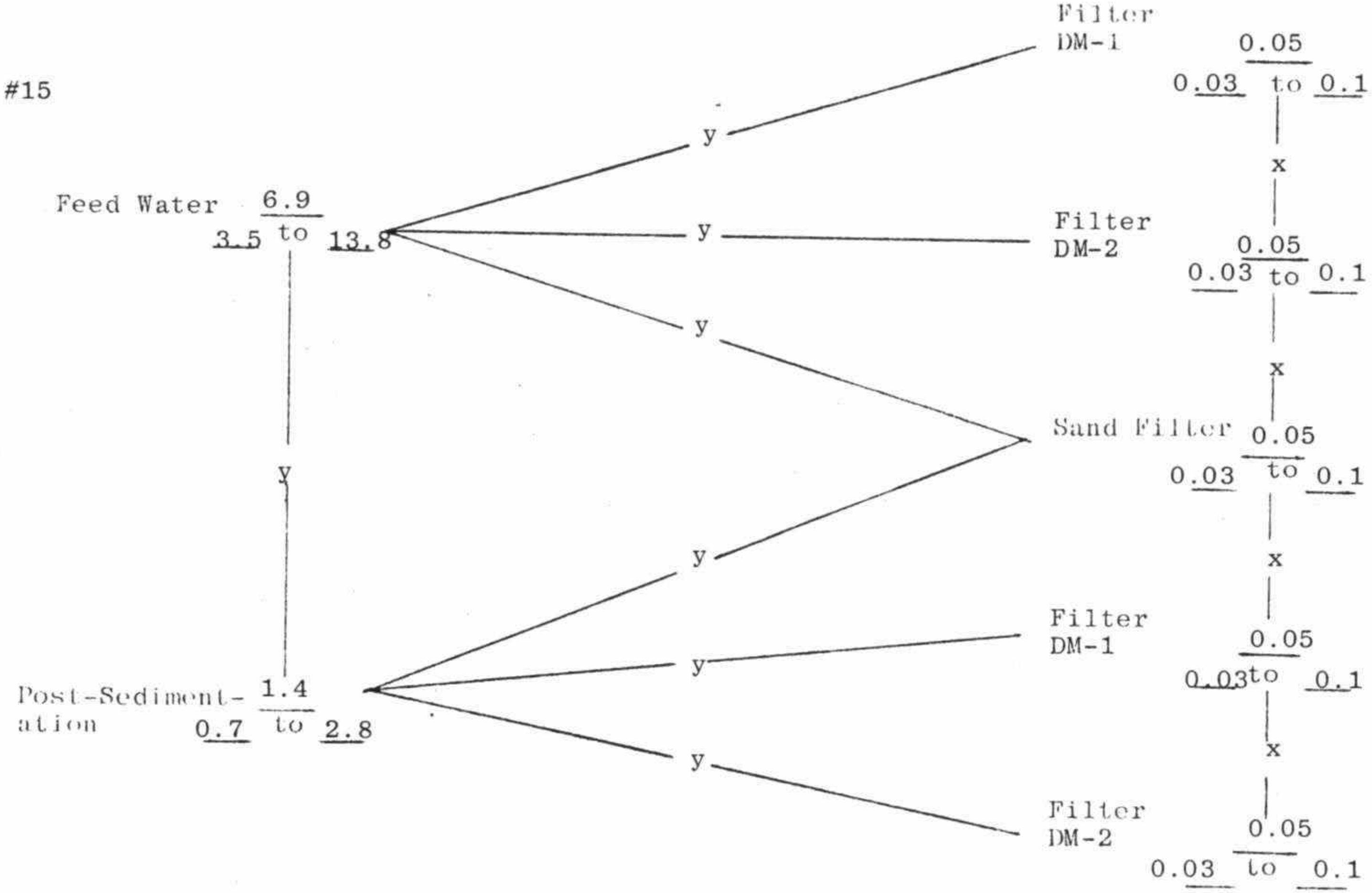
"x" denotes that no significant difference exists between the two asbestos counts given the range dictated by the factor of 2.

"y" denotes that a significant difference exists between the two asbestos counts given the range dictated by the factor of 2.

* all asbestos counts are given in fibres $\ell^{-1} \times 10^6$

MOE/CCIW PILOT PLANT STUDY
ASBESTOS FIBRE COUNTS * AND
THEIR SIGNIFICANCE, GIVEN A
UNCERTAINTY FACTOR OF 2

Run #15



Notes

"x" denotes that no significant difference exists between the two asbestos counts given the range dictated by the factor of 2.

"y" denotes that a significant difference exists between the two asbestos counts given the range dictated by the factor of 2.

* all asbestos counts are given in fibres $\ell^{-1} \times 10^6$